
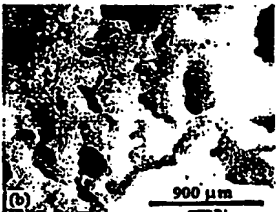





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<b>(54) Title:</b> POROUS CERAMIC COMPOSITES		
<b>(57) Abstract</b>		
<p>The present invention relates to ceramic compositions and to the highly porous ceramic formed from such compositions. The highly porous ceramics may be milled to form granules of a particular size and shape, thus making them useful for various applications, particularly biomedical applications. Optionally, the highly porous ceramics may be fiber reinforced such that they have significantly improved compressive strengths and toughness over other ceramic compositions, particularly those used for biomedical applications.</p> <div style="display: flex; justify-content: space-around; align-items: flex-end;">    </div>		

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## POROUS CERAMIC COMPOSITES

### BACKGROUND OF THE INVENTION

The present invention relates generally to ceramic compositions and, more particularly, to highly porous ceramics made from such compositions which have improved compressive strength and toughness. The invention  
5 also relates to the methods of manufacturing the highly porous ceramics of the present invention.

### DESCRIPTION OF THE ART

Due to their chemical inertness and stability at high temperatures, the  
10 desire for porous ceramics has increased dramatically in recent years. A relatively recent trend in the porous ceramic art has been its attempted use in bone substitution processes. The porous ceramics used in bone substitution often are made of a calcium phosphate composition of the formula  $[\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$  with a Ca:P ratio of approximately 1:0.6. This  
15 composition is generally referred to as hydroxyapatite (HA).

Hydroxyapatite is known to have superior biocompatibility, that is, it is known to be chemically similar to human bone and is considered to be an active promoter of bony in-growth, i.e., bio-active. To be useful in bone substitution applications, it is important for the organic matrix adjacent to the  
20 implant to receive calcium and phosphorous which are necessary for mineralization. These are supplied through the infiltration of a vascular

network. Thus, macropores of between 200 and 400  $\mu\text{m}$  are generally considered to be necessary to allow filtration of cellular and vascular components of bone and blood vessels. Since ceramics having an open porosity in the above mentioned range are thought to have a structure closely  
5 related to cancellous bone which is subsequently converted to cortical bone through a progressive deposition of new bone lamellae by a series of osteons, a suitable porous ceramic implant will create the conditions necessary for this deposition. While micropores in the range of 40 - 100  $\mu\text{m}$  have been shown to allow the in-growth of unmineralized osteoid tissue and  
10 pores of 15 - 40  $\mu\text{m}$  permit fibrous tissue penetration, to provide the development of osteons the pore size must generally be at least 200  $\mu\text{m}$  but not larger than 400  $\mu\text{m}$ .

In view of the foregoing, it is desirable to increase the adsorption area by providing micropores in the macropore structure wall. This may promote  
15 cellular adhesion and differentiation. Interconnected micropores are also important in allowing the flow of body fluid (nutritional supply) between the macropores to promote the growth of the bone in the macropores of an implant.

While porous ceramics are considered to be useful for bone  
20 substitution applications, a perceived problem with using porous hydroxyapatite (HA) ceramics for bone substitutes is their lack of strength and toughness, which necessarily limits their usage to non-load bearing areas. Accordingly, the present invention relates in part to structurally reinforced

porous HA ceramic compositions. Reinforcing porous HA ceramics with short and/or continuous fibers will increase the strength and toughness, to approach values needed for load-bearing human bone applications.

A potential problem with using fibers, however, is the chance for  
5 resorption of the matrix and subsequent release of the fibers into the surrounding tissues. This is particularly true since HA (especially the partially sintered form of HA called tricalcium phosphate TCP) is thought to partially resorb in a physiological environment over time and porous HA provides increased surface area as compared to other dense ceramics. With the  
10 release of fibers, localized tissue inflammation may result with non-biocompatible reinforcements and/or fiber migration. To minimize the potential for reaction, it is necessary to choose a material with superior biocompatibility and the ability to chemically bond to the matrix.

Another perceived problem with utilizing porous HA ceramics and  
15 particularly short or continuous fiber reinforced HA ceramics is the lack of quality processing methods offered in the art. For example, previous methods for fabricating porous ceramics have included impregnating polymeric sponges having interconnected macropores with a ceramic slurry to obtain a structure replicating that of the sponge. The polymeric sponge  
20 method, however, is work intensive and requires binders, to provide adequate green strength and to prevent collapse of the sponge during the gas evolution stage, along with anti-foaming and rheological agents.

Binders, such as aluminum orthophosphate, sodium silicate or magnesium orthoborate can leave behind residual phosphates which are susceptible to chemical attack. Residual binders, as well as anti-foaming agents and rheological agents which are useful for improving wettability, can  
5 elicit tissue reactions, cause localized inflammation, pain and may lead to rejection of the implant by the body.

Another known method involving the process of forming HA ceramics includes manufacturing porous HA sheets by a tape casting technique with a gas forming agent such as  $\text{CaCO}_3$ . While the resulting ceramic had a  
10 relatively high porosity, i.e., up to about 62%, the pore diameter was limited to only a few microns.

Another known process of producing porous HA ceramics is via a lost wax process which uses a negative wax replica of a porous skeletal microstructure, filled with a ceramic slurry. The wax burns off during firing,  
15 leaving behind macropores. Although successful in terms of producing pores of a known dimension, this process is time and equipment intensive, requiring specialty manufacturing equipment. Reinforcing additives, which are often required, are limited to materials which can be easily impregnated into the pores of the skeleton and for the case of *in vivo* use, are biocompatible.  
20 Uniformity in the distribution of reinforcing fibers is also considered to pose a potential problem.

One other known method of fabricating porous HA ceramics involves the mixing of ceramic powders with a polymeric powder followed by uniaxial

die-pressing. The polymeric particles are removed by heating which initially leaves pores of identical size and shape of the particles. However, the pores tend to become distorted as a result of the die pressing. Again, this method is considered to be unnecessarily labor intensive and the subsequent binder burn-off process leaves a carbon residue contaminant.

In view of the foregoing, there is a need for a readily repeatable processing method for fabricating highly porous ceramics of controlled pore size which offers improved compressive strength and toughness. Further, there is a definite need for highly porous ceramics which are biocompatible.

10

### SUMMARY OF THE INVENTION

The present invention is thus directed to porous ceramic composites and to methods for fabricating porous ceramic composites. The porous ceramics composites of the present invention are generally made according to the following method in which an electrolyte solution such as  $10^{-3}\text{M}$   $\text{KNO}_3$  electrolyte including approximately 30% by volume of concentrated  $\text{H}_2\text{O}_2$  is originally provided. Added to this electrolyte solution, preferably with constant mixing is a particulate material selected from the group consisting essentially of relatively fine alumina powder having an average particle size of between about  $0.2\ \mu\text{m}$  to about  $0.6\ \mu\text{m}$ , hydroxyapatite powder having an average particle size of between about  $6.0\ \mu\text{m}$  to about  $14.0\ \mu\text{m}$  and mixtures thereof. Thereafter, reinforcing fibers selected from the group consisting essentially of  $\text{Al}_2\text{O}_3$  and hydroxyapatite fibers are optionally added to the composition in

an amount of up to about 8.0 percent by volume of the solid portion of the composite. Generally, the fibers, whether short or continuous, are added directly to the composite under constant mixing at ambient temperatures until a creamy suspension (slurry) is obtained.

5           The creamy suspension is then introduced into molds having the desired shape and covered with a porous foil which serves to assist in regulating the pore size and uniformity of pore distribution while simultaneously allowing the evolving gas to escape. The composition is then placed in a drying furnace to obtain the porous "green structure". With  
10 heating, the hydrogen peroxide breaks down into water and free oxygen. The free oxygen bubbles up through the sample creating the interconnected porous structure in its wake. The dried samples are cooled in air at room temperature and the samples are sintered to obtain a hardened structure. Optionally, the resulting porous ceramic can be milled to form granules of a  
15 desired size and shape, thus allowing the granules to be used for a variety of applications.

As alluded to above, in order to be useful in bone substitution applications, proper blood conveyance throughout the ceramic is of major importance as the blood supplies the calcium and phosphorous needed for  
20 the mineralization of the organic matrix as well as providing the humoral substrate which enables the internal tissue to grow. Thus, macropores of between 200 and 400  $\mu\text{m}$  are generally considered to be necessary to allow filtration of cellular and vascular components of bone and blood vessels. By



controlling processing parameters such as the starting powder and fiber amounts if employed, pores having diameters in this range can be obtained.

Since ceramics having an open porosity in the above mentioned range are thought to have a structure closely related to cancellous bone which is subsequently converted to cortical bone through a progressive deposition of new bone lamellae by a series of osteons, the fiber reinforced porous HA ceramics of the present invention are believed to be ideal candidates for biocompatible implants.

Micropores in the macropore structure wall increases the adsorption areas and may provide a favorable surface for cellular adhesion and differentiation. Interconnected micropores are also important in allowing the flow of body fluid (nutritional supply) between the macropores to promote the growth of the bone in the macropores. Microstructural evaluation of these composites shows interconnected microporosity.

15

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1a is a stereomicrograph showing the microstructure of an  $\text{Al}_2\text{O}_{3(n)}/\text{Al}_2\text{O}_3$  composite;

Figure 1b is a stereomicrograph showing the microstructure of an  $\text{Al}_2\text{O}_{3(n)}/\text{HA}$  composite;

Figure 1c is a stereomicrograph showing the microstructure of an  $\text{HA}_{(n)}/\text{HA}$  composite;

Figure 2 is a stereomicrograph of a  $\text{Al}_2\text{O}_{3(f)}/\text{HA}$  composite depicting the microporous structure;

Figure 3 is a graph plotting pore diameter as a function of HA powder volume percent;

5        Figure 4 is a graph plotting pore diameter as a function of fiber volume percent;

Figure 5 is a graph plotting percent porosity as a function of fiber volume percent;

10       Figure 6 is a graph plotting pore diameter as a function of  $\text{H}_2\text{O}_2$  content in  $\text{Al}_2\text{O}_{3(f)}/\text{HA}$  composites; and

Figure 7 is an energy spectrum of an  $\text{Al}_2\text{O}_{3(f)}/\text{HA}$  composite from energy dispersive spectroscopy.

### **DETAILED DESCRIPTION OF THE INVENTION**

15       One aspect of the present invention generally relates to a method for fabricating a porous ceramic composite. The method includes as a first step providing a) an electrolyte solution having a suitable pH. The electrolyte solution is generally selected from the group consisting essentially of NaCl, LiCl,  $\text{CaCl}_2$ ,  $\text{NH}_4\text{Cl}$ ,  $\text{MgCl}_2$ ,  $\text{BaCl}_2$ ,  $\text{Ca}(\text{NO}_3)_2$ ,  $\text{MgSO}_4$ ,  $\text{K}_2\text{SO}_4$ ,  $\text{NaNO}_3$ ,  $\text{ZnCl}_2$ ,  
20        $\text{K}_2\text{Cr}_2\text{O}_7$ ,  $\text{Na}_2\text{PO}_4$ ,  $\text{AlCl}_3$ ,  $\text{KNO}_3$ ,  $\text{Al}_2(\text{SO}_4)_3$ , KCl, and  $\text{Ce}(\text{NO}_3)_3$ , by way of non-limiting example.

The electrolyte concentrations range from  $10^{-7}\text{M}$  to 4.0 M, depending on the particulate and fiber component employed. For instance, an

electrolyte such as  $10^{-3}\text{M}$   $\text{KNO}_3$  including a 30% concentration of  $\text{H}_2\text{O}_2$  is useful for ceramic composites comprised of hydroxyapatite particles and hydroxyapatite fibers. Additionally, 0.154 M NaCl is useful for interactions between titanium and hydroxyapatite.

5           The next step of the method involves adding between about 20.0 volume percent to about 35.0 volume percent of a relatively fine particulate material b) selected from the group consisting essentially of alumina powder, hydroxyapatite powder or mixtures thereof to the solution a) while stirring the same. Preferably the alumina powder will have an average particle size of  
10   between about 50 nanometers (nm) to about 100 micrometers ( $\mu\text{m}$ ), with a range of 0.2  $\mu\text{m}$  to 0.6  $\mu\text{m}$  being preferred. Alumina powders ( $\text{Al}_2\text{O}_3$ ) such as those marketed by Sumitomo Chemical Co. Ltd. under the trade designation AKP-30 and AKP-50 have been found to be particularly useful.

          The hydroxyapatite powders preferably will have an average particle  
15   size of between about 0.1  $\mu\text{m}$  to about 100  $\mu\text{m}$ , with a range of 6  $\mu\text{m}$  to about 14  $\mu\text{m}$  being preferred. Hydroxyapatite particles such as those offered commercially by Hitemco Medical Appliances, Inc. have been found to be particularly useful.

          Optionally, a fiber component c) may be added to the solution before  
20   sintering. While any suitable biocompatible fiber may be employed, fibers selected from the group consisting essentially of alumina fibers, hydroxyapatite fibers or mixtures thereof are preferred. The total amount of fibers added will be an amount sufficient to form a relatively pasty slurry. In

this regard, it has been found up to about 8.0% by volume of the solid portion of the fibers are suitable, with a range of 4.0% volume to 5.0% by volume being preferred. The alumina fibers, if employed, may be continuous or may be chopped to an average length of less than about 10 mm. More preferably, the short alumina fibers will have an average length of between about 0.5 mm to about 7.0 mm, with a range of between about 1.0 mm to about 3.0 mm being most preferred. The alumina fibers will also preferably have an average diameter of less than 1.0 mm. More preferably, the alumina fibers will have an average diameter of between about 5.0  $\mu\text{m}$  to about 300  $\mu\text{m}$  with a range of between about 10  $\mu\text{m}$  to about 14  $\mu\text{m}$  being most preferred. Such fibers are available from the 3M Corporation under the trade designation NEXTEL  $\text{Al}_2\text{O}_3$  fibers.

Likewise, the hydroxyapatite fibers, if employed, may be in the form of the continuous fibers or may be chopped such that they will have an average length of less than 10 mm. More preferably, the short hydroxyapatite fibers will have an average length of between about 0.5 mm to about 7.0 mm, with a range of between about 1.0 mm to about 3.0 mm being most preferred. The hydroxyapatite fibers will also have an average diameter of less than 1.0 mm. More preferably, the hydroxyapatite fibers will have an average diameter of between about 5.0  $\mu\text{m}$  to about 300  $\mu\text{m}$ , with a range of 150  $\mu\text{m}$  to 200  $\mu\text{m}$  being most preferred.

The hydroxyapatite fibers can be made by a simple extrusion method, by way of non-limiting example. The method includes first, dissolving

polyethylene glycol (PEG) in 200 proof ethanol while heating. Hydroxyapatite powder is added at a ratio of 1 part PEG to 3 parts hydroxyapatite powder (1:3). The slurry is stirred until enough ethanol has evaporated off to provide the desired viscosity. The mixture is then placed into a 3 cc syringe fitted  
5 with a 25 gage needle to extrude the fibers out. The fibers are dried at room temperature in air for 24 hours followed by sintering in air at 1350° C for two hours.

The slurry resulting from the combination of a), b) and optionally c) is then poured into castings having the desired shape and covered with a  
10 porous metal foil. The foil allows evolving gases to escape while acting to maintain a constant slurry volume and controlling the pore size and uniformity of pore distribution. Absent the foil, the slurry tends to foam out and retract, resulting in a non-uniform ceramic product having uncontrolled pore size and an uneven pore distribution.

15 Upon properly covering the castings, the composition is placed in a drying furnace to drive off moisture, thus forming a ceramic shell. The shell is then allowed to cool to room temperature and is subsequently sintered. As should be understood by those skilled in the ceramics art, the drying times, cooling times and time and temperatures required for sintering the ceramics  
20 is material, shape and volume dependent.

Under an alternative embodiment of the present invention, the resulting porous ceramic, particularly the non-fiber reinforced porous ceramics, can be milled such that the granules having a specifically desired size and shape are

obtained. Once obtained, the granules can be used for a number of different applications including but not limited to bone fillers, i.e. filling holes left by bone cysts, bone screws, etc. To be used as bone fillers it is preferred that the granules have an average size of between about 1.0 mm to about 2.0 mm.

In addition to bone replacement applications, it should be understood that the porous compositions employing alumina particulate and/or alumina fibers can be employed to form molten metal filters, fuel sessions and catalyst supports by way of non-limiting example. Further, the ceramic compositions employing alumina particulate and alumina fibers may be used for bone replacement applications since it is considered to be bioinert.

By way of non-limiting example, slurry samples were prepared as shown in Table 1 below and were placed into cylindrical shaped castings having a depth of 2.5 cm and a diameter of 2.5 cm. The samples were dried for 3.0 hours at 120° C in air and thereafter allowed to cool to room temperature. The samples were then sintered for 1.0 hour at 1600° C for  $\text{Al}_2\text{O}_{3(f)}/\text{Al}_2\text{O}_3$  compositions and for 2.0 hours at 1375° C for  $\text{Al}_2\text{O}_{3(f)}/\text{HA}$  and  $\text{HA}_{(f)}/\text{HA}$  compositions, wherein (f) is indicative of a fiber component.

After preparing the samples set forth in Table 1, the samples were sectioned using a diamond edged cutting wheel. The pore diameters were measured using a stereo microscope and the pore volume for each sample was determined using Archimedes method. Finally, the samples were examined for chemical purity using energy dispersive spectroscopy (EDS).

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Table I

Sample No.	Al <sub>2</sub> O <sub>3</sub> powder content (g)	HA powder content (g)	Al <sub>2</sub> O <sub>3</sub> fiber content (g)		10 <sup>-3</sup> M KNO electrolyte (ml)	H <sub>2</sub> O <sub>2</sub> content (ml)	macropore (μm)	micropore (μm)	density (μm)	% porosity	Powder vol.%	H <sub>2</sub> O <sub>2</sub> vol. %	Fiber vol. %
			1 mm length	2 mm length									
1	6.0		0.15		3.6	2.7	250	60.4	0.96	76	19.0		
2	6.6		0.165		3.6	2.7	210	57	0.67	83.3	21.0		
3	7.26		0.181		3.6	2.7	200	45	0.59	85.2	22.0		
4	7.986		0.199		3.6	2.7	195	52	0.63	84.1	24.0		
5		6.0	0.25		4.2	3.3	316	53	0.708	77		35.0	
6		6.0	0.25		2.7	3.6	340	54	0.68	78.2		43.0	
7		6.0	0.25		2.5	4.5	367	53	0.85	73		50.0	
8		6.0	0.25		4.2	2.5	426	41	0.76	76		29.0	
9		7.75		0.2	3	4.0	286	63	1.048	66			2.5
10		7.75		0.25	3	4.0	338	42	0.825	74			3.0
11		7.75		0.3	3	4.0	378	63	0.79	75			4.0
12		7.75		0.35	3	4.0	392	53	0.771	75			4.3

Table 1 is a listing of "typical" values of reactant components and their corresponding results (i.e., micro/macro-porosity, density, etc.

While it will be apparent that the preferred embodiments of the invention disclosed are well calculated to fulfill the objects stated, it will be appreciated that as the invention is susceptible to modification, variation and change without departing from the spirit thereof.



**WHAT IS CLAIMED IS:**

5           1.     A reinforced porous ceramic comprising:

          a particulate material selected from the group consisting essentially of  
alumina powder, hydroxyapatite powder and mixtures thereof; and

          a fiber component in the form of fibers present in an amount of up to  
about 8.0 volume % based on the total solids percent.

10           2.     The reinforced porous ceramic of Claim 1 wherein said fiber  
component is present in an amount of between about 4.0 volume % to about  
5.0 volume % based on the total solids percent.

15           3.     The reinforced porous ceramic of Claim 1 wherein said fiber  
component is selected from the group consisting essentially of alumina fibers,  
hydroxyapatite fibers and mixtures thereof.

20           4.     The reinforced porous ceramic of Claim 3 wherein said fibers  
have an average length of between about 1.0 mm to about 3.0 mm.

          5.     The reinforced porous ceramic of Claim 3 wherein said  
hydroxyapatite fibers have an average diameter of between about 150  $\mu\text{m}$  to  
about 300  $\mu\text{m}$ .

6. The reinforced porous ceramic of Claim 3 wherein said alumina fibers have an average diameter of between 5  $\mu\text{m}$  to about 300  $\mu\text{m}$ .

5 7. The reinforced porous ceramic of Claim 1 wherein said particulate material has an average particle size of up to about 100  $\mu\text{m}$ .

8. The reinforced porous ceramic of Claim 7 wherein said particulate material has an average particle size of about 100  $\mu\text{m}$ .

10 9. The reinforced porous ceramic of Claim 1 wherein said porous ceramic has an average micropore size of at least 15.0  $\mu\text{m}$ .

10. The reinforced porous ceramic of Claim 9 wherein said porous ceramic has an average macropore size of at least 150  $\mu\text{m}$ .

15 11. The reinforced porous ceramic of Claim 1 wherein said porous ceramic has an average macropore size of at least 150  $\mu\text{m}$ .

20 12. The reinforced porous ceramic of Claim 11 wherein said porous ceramic has an average macropore size between about 200  $\mu\text{m}$  to about 500  $\mu\text{m}$ .

13. A method of forming a porous ceramic component comprising the steps of:

- a) providing an electrolyte solution;
- b) admixing into the electrolyte solution a particulate material selected from the group consisting essentially of alumina powder, hydroxyapatite powder and mixtures thereof to obtain a slurry;
- c) covering said slurry with a porous metallic foil to allow evolving gas to escape;
- d) heating said slurry to drive off moisture, thereby forming a porous ceramic shell;
- e) cooling said ceramic shell until the shell temperature is below about 25° C; and
- f) sintering the ceramic shell to obtain the porous ceramic component.

14. The method of Claim 13 wherein said electrolyte solution is selected from the group consisting of NaCl, LiCl, CaCl<sub>2</sub>, NH<sub>4</sub>Cl, MgCl<sub>2</sub>, BaCl<sub>2</sub>, Ca(NO<sub>3</sub>)<sub>2</sub>, MgSO<sub>4</sub>, K<sub>2</sub>SO<sub>4</sub>, NaNO<sub>3</sub>, ZnCl<sub>2</sub>, K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>, Na<sub>2</sub>PO<sub>4</sub>, AlCl<sub>3</sub>, KNO<sub>3</sub>, Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, KCl and Ce(NO<sub>3</sub>)<sub>3</sub>.

15. The method of Claim 12 wherein said electrolyte solution comprises 10<sup>-3</sup>M KNO<sub>3</sub> including about 30% by volume of concentrated H<sub>2</sub>O<sub>2</sub>.

16. The method of Claim 13 comprising the additional step g) of milling the sintered porous ceramic to obtain granules.

17. The method of Claim 16 wherein said granules have an average size of between about 1.0 mm and 2.0 mm.

18. The method of Claim 16 wherein said granules are useful as bone fillers.

19. The method of Claim 13 comprising an additional step after b) but before c) of adding a fiber component in an amount of up to about 8.0 volume % based on the total solids volume.

20. The method of Claim 19 wherein said fiber component is present in an amount of between about 4.0 volume % to about 5.0 volume % based on the total solids percent.

21. The method of Claim 19 wherein said fiber component is selected from the group consisting essentially of alumina fibers, hydroxyapatite fibers and mixtures thereof.

22. The method of Claim 19 wherein said fibers have an average length of at least about 1.0 mm.

23. The method of Claim 19 wherein said hydroxyapatite fibers have an average diameter of between about 150  $\mu\text{m}$  to about 200  $\mu\text{m}$ .

24. The method of Claim 19 wherein said hydroxyapatite particulate material has an average particle size of from about 6  $\mu\text{m}$  to about 14  $\mu\text{m}$ .

25. The method of Claim 19 wherein said alumina particulate material has an average particle size of from about 0.2  $\mu\text{m}$  to about 0.6  $\mu\text{m}$ .

26. The method of Claim 13 wherein said porous ceramic has an average micropore size of at least 15.0  $\mu\text{m}$ .

27. The method of Claim 26 wherein said porous ceramic has an average micropore size of between about 45.0  $\mu\text{m}$  to about 75.0  $\mu\text{m}$ .

28. The method of Claim 13 wherein said porous ceramic has an average macropore size of at least 150  $\mu\text{m}$ .

29. The method of Claim 28 wherein said porous ceramic has an average macropore size of between about 200  $\mu\text{m}$  to about 500  $\mu\text{m}$ .

**AMENDED CLAIMS**

[received by the International Bureau on 04 April 2000 (04.04.00);  
original claims 1-29 replaced by amended claims 1-23 (5 pages)]

**WHAT IS CLAIMED IS:**

1. A reinforced porous bone substitution ceramic comprising:

a hydroxyapatite powder having an average particle size of between about 0.1  $\mu\text{m}$  and 100  $\mu\text{m}$ ; and

a fiber component in the form of inorganic fibers present in an amount of  
5 between about 0.5 volume % to about 8.0 volume % based on the total solids percent;

wherein said porous ceramic has a macropore size of at least 150  $\mu\text{m}$ , a micropore size of at least 15  $\mu\text{m}$  and a total porosity of at least 60%.

10 2. The reinforced porous bone substitution ceramic of Claim 1 wherein said fiber component is present in an amount of between about 4.0 volume % to about 5.0 volume % based on the total solids percent.

3. The reinforced porous bone substitution ceramic of Claim 1 wherein  
15 said fiber component is selected from the group consisting essentially of alumina fibers, hydroxyapatite fibers and mixtures thereof.

4. The reinforced porous bone substitution ceramic of Claim 3 wherein said fibers have an average length of between about 1.0 mm to about 3.0 mm.

5. The reinforced porous bone substitution ceramic of Claim 3 wherein said hydroxyapatite fibers have an average diameter of between about 150  $\mu\text{m}$  to about 300  $\mu\text{m}$ .

5 6. The reinforced porous bone substitution ceramic of Claim 3 wherein said alumina fibers have an average diameter of between 5  $\mu\text{m}$  to about 300  $\mu\text{m}$ .

7. The reinforced porous bone substitution ceramic of Claim 1 wherein said porous ceramic has an average micropore size of between about 45.0  $\mu\text{m}$  to  
10 about 75.0  $\mu\text{m}$ .

AMENDED SHEET (ARTICLE 19)

8. A method of forming a porous ceramic component comprising the steps of:

- a) providing an electrolyte solution;
- b) admixing into the electrolyte solution a particulate material selected  
5 from the group consisting of alumina powder, hydroxyapatite powder and mixtures thereof to obtain a slurry;
- c) adding a fiber component in the form of inorganic fibers present in an amount of between 0.5 volume % to about 8.0 volume % based on the total solids percent;
- 10 d) covering said slurry with a porous metallic foil to allow evolving gas to escape;
- e) heating said slurry to drive off moisture, thereby forming a porous ceramic shell;
- f) cooling said ceramic shell until the shell temperature is below about 25°  
15 C; and
- g) sintering the ceramic shell to obtain the porous ceramic component.

9. The method of Claim 8 wherein said electrolyte solution is selected from the group consisting of NaCl, LiCl, CaCl<sub>2</sub>, NH<sub>4</sub>Cl, MgCl<sub>2</sub>, BaCl<sub>2</sub>, Ca(NO<sub>3</sub>)<sub>2</sub>,  
20 MgSO<sub>4</sub>, K<sub>2</sub>SO<sub>4</sub>, NaNO<sub>3</sub>, ZnCl<sub>2</sub>, K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>, Na<sub>2</sub>PO<sub>4</sub>, AlCl<sub>3</sub>, KNO<sub>3</sub>, Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, KCl and Ce(NO<sub>3</sub>)<sub>3</sub>.



10. The method of Claim 9 wherein said electrolyte solution comprises 10<sup>-3</sup>M KNO<sub>3</sub> including about 30% by volume of concentrated H<sub>2</sub>O<sub>2</sub>.

11. The method of Claim 8 comprising the additional step h) of milling the  
5 sintered porous ceramic to obtain granules.

12. The method of Claim 8 wherein said granules have an average size of  
between about 1.0 mm and 2.0 mm.

10 13. The method of Claim 8 wherein said granules are useful as bone fillers.

14. The method of Claim 8 wherein said fiber component is present in an  
amount of between about 4.0 volume % to about 5.0 volume % based on the total  
solids percent.

15

15. The method of Claim 14 wherein said inorganic fiber component is  
selected from the group consisting essentially of alumina fibers, hydroxyapatite  
fibers and mixtures thereof.

20

16. The method of Claim 14 wherein said inorganic fibers have an average  
length of at least about 1.0 mm.

AMENDED SHEET (ARTICLE 19)

17. The method of Claim 14 wherein said hydroxyapatite fibers have an average diameter of between about 150  $\mu\text{m}$  to about 200  $\mu\text{m}$ .

18. The method of Claim 14 wherein said hydroxyapatite particulate  
5 material has an average particle size of from about 6  $\mu\text{m}$  to about 14  $\mu\text{m}$ .

19. The method of Claim 14 wherein said alumina particulate material has an average particle size of from about 0.2  $\mu\text{m}$  to about 0.6  $\mu\text{m}$ .

10 20. The method of Claim 8 wherein said porous ceramic has an average micropore size of at least 15.0  $\mu\text{m}$ .

21. The method of Claim 21 wherein said porous ceramic has an average micropore size of between about 45.0  $\mu\text{m}$  to about 75.0  $\mu\text{m}$ .

15

22. The method of Claim 8 wherein said porous ceramic has an average macropore size of at least 150  $\mu\text{m}$ .

23. The method of Claim 23 wherein said porous ceramic has an average  
20 macropore size of between about 200  $\mu\text{m}$  to about 500  $\mu\text{m}$ .

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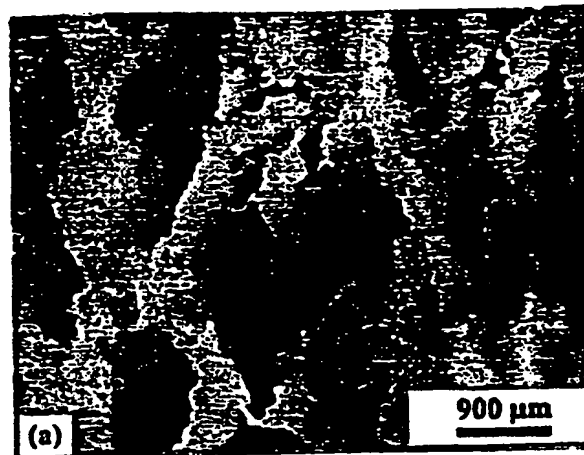


Fig. 1a

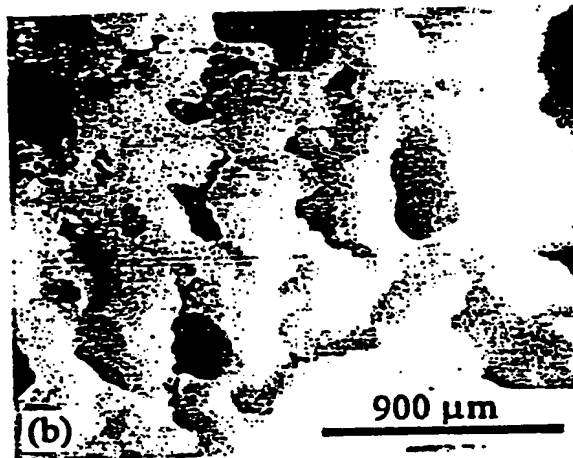


FIG. 1b

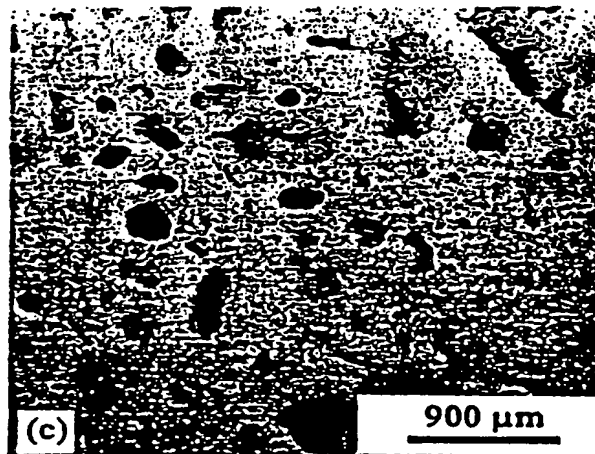


FIG. 1c

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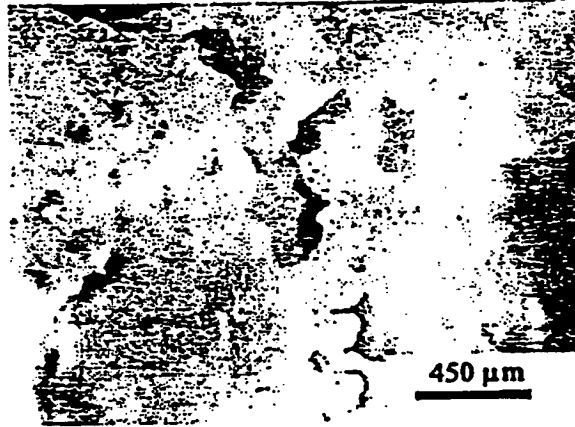


FIG. 2

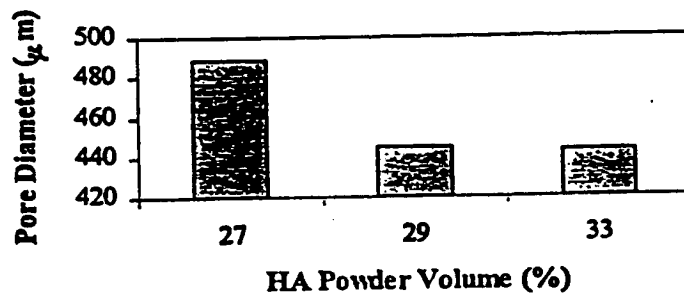


FIG. 3

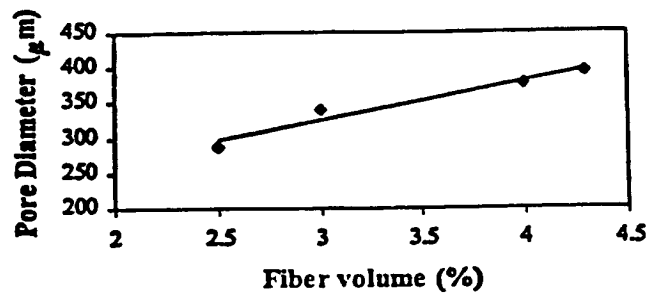


FIG. 4

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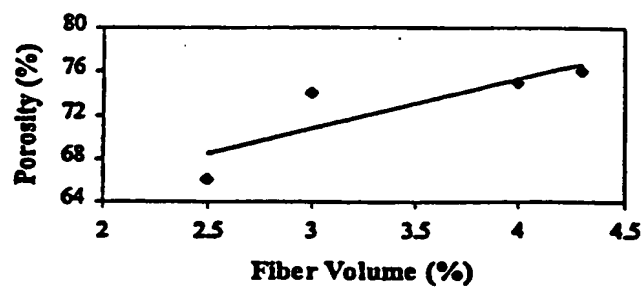


FIG. 5

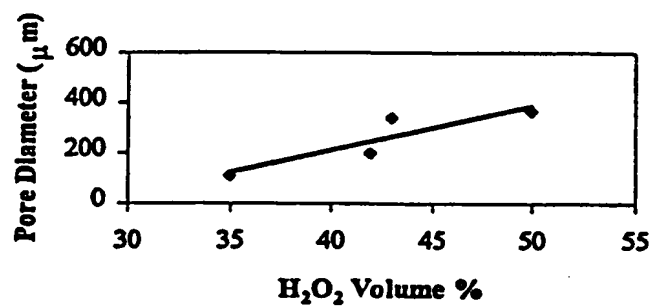
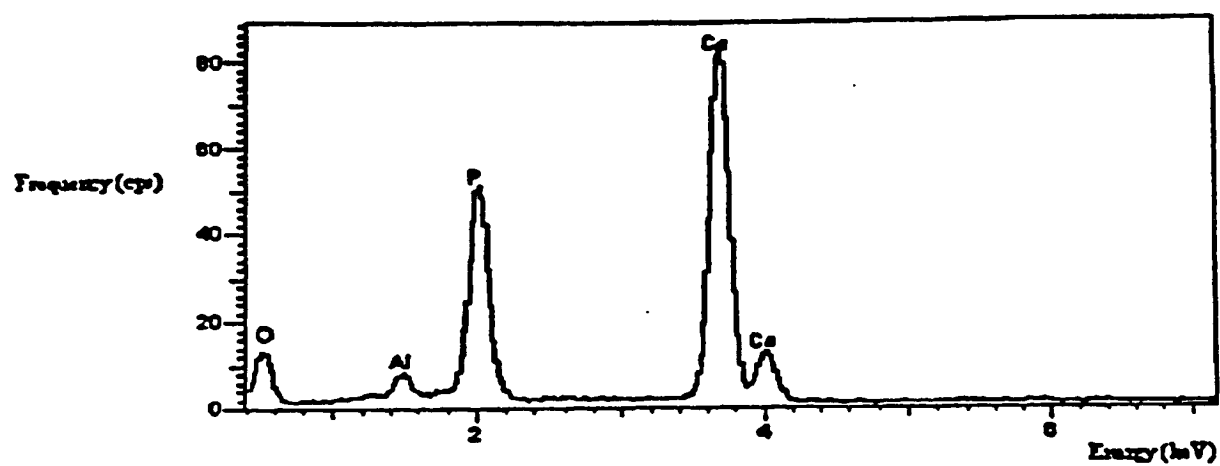


FIG. 6

*Fig. 7*

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US99/27378

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :C04B 35/00

US CL :501/1, 80; 623/16

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : CO4B 35/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CAS-CHEMICAL ABSTRACTS

SEARCH TERMS: HYDROXYAPATITE, ALUMINA, POROUS

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,629,464 A (TAKATA ET AL.) 16 December 1986, claims 1-7 in columns 11-12	1-29
Y	US 4,861,733 A (WHITE) 29 AUGUST 1989, claims 1-18 in columns 13-14.	1-29
Y	US 5,030,611 A (OGAWA ET AL.) 09 JULY 1991, claims 1-10 in columns 7-8.	1-29
Y	US 3,929,971 A (ROY) 30 December 1975, see claims 1-26 in columns 9-10.	1-29

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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*O* document referring to an oral disclosure, use, exhibition or other means	
*P* document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

24 JANUARY 2000

Date of mailing of the international search report

09 FEB 2000 (09.02.00)

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